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HydroFlex

AFC 4 HYDRO

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E-mail:
ole.g.dahlhaug@ntnu.no
wp5@afc4hydro.eu

Web:
h2020hydroflex.eu
afc4hydro.eu

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GREETINGS

FROM AFC4HYDRO WP2 LEADER MORTEN KJELDSEN

Welcome to WP2- Injection of Continuous Momentum (ICM).

WP2 is run by Flow Design Bureau AS (FDB) from Norway, the SME partner of the project AFC4Hydro. FDB has always participated in R&D projects, and many of our employees have a PhD degree an even obtained it while being employed and working on FDB projects. Our participation in the AFC4Hydro project therefore fits our profile.

FDB
Flow Design Bureau

The work on ICM dates to 2005(!) when a first attempt was made on shooting water tangentially into the draft tube cone in a 4MW Francis turbine for the mitigation and the control of pressure pulsations on the low-pressure side of such turbines.
This technology, in AFC4Hydro termed as 1st generation ICM, was scrutinized in a PhD delivered by FDB's Håkon Francke in 2010.
Over the years 4 installations of the 1st generation ICM went into operation, and where the biggest unit is at 370 meters head and with a rated output of 130MW.
In some of these installations it became evident that the overall performance of the system likely benefits from more degrees of freedom (DOF) during operation.

In AFC4Hydro the increase of DOFs for the ICM is one of the main objectives for WP2. In addition, the AFC4Hydro allows the validation of the ICM technology over several scales, and the use of ICM in Kaplan type turbines.

For FDB a major benefit is to work closely, and over four years, with academic institutions and operators of hydropower and toward the same objective of making hydropower even more relevant in the European energy-mix. FDB also appreciates that many tasks of the AFC4Hydro project are very technical oriented; design of flow systems, mechanical construction, and advanced approaches to measurement, all of which further increase our competency and company body of knowledge.

Figure 1. FDB personnel working toghether with other AFC4Hydro partners.

WP2 leader
Prof. Morten Kjeldsen,
General Manager
Flow Design Bureau AS

2 | GREETINGS

FROM HYDROFLEX INDUSTRY PARTNER EDR MEDESO

With increased intermittent energy sources, the role and value-add of hydropower has never been more important. To meet the future demand and markets; being able to simulate, optimize and foresee various future scenarios impact on the turbine design and lifetime is hence of high importance.

EDR MEDESO

EDRMedesos role in HydroFlex is to develop tools within our Digital Lab concept to close this technology gap. The Digital Labs consists of a collection of software, services and processes that enhance innovation and enables companies to virtually test various future scenarios. By utilizing the digital lab, industries can not only optimize but also make a significantly greener environmental impact throughout the lifecycle – from early R&D to end of life.

Concrete, what we do in this project is to utilize the research and experimental data and combine it with engineering know how and existing technology tools to compile an automated parametric design tool. Hydraulic efficiency and structural stresses are calculated at various operating points to get the "full picture". From there the optimization starts and the output is optimized design based on user preferred input.

EDRMedeso has a strong tradition of participating in research projects like this. We are a software vendor, but we are also a competence center with deep industrial know how in various verticals such as Hydropower. In cases like this we like to see ourselves as a natural link between academia, the research forefront, and the industry. Adding the competence value to our software delivery is important ingredient to what we deliver, and hence such research projects are important for us to gain knowledge and contribute to.

Martin Aasved Holst
Group Manager,
Digital Labs

AFC4HYDRO ACTIVITIES

3

TESTING IN ÄLVKARLEBY

VATTENFALL

Carl-Maikel Högström, Vattenfall AB, R&D

The measuring campaign in Vattenfall test facility located in Älvkarleby, Sweden started September 13th 2021 and will continue until the end of this year. The preparation for these tests has however been going on for a long time and started already in 2018. Vattenfall has not only prepared and upgraded the test rig for transient turbine operation, including a new digitalized control system, but has also designed and manufacturing the Kaplan model turbine to be used for both internal research and for the AFC4HYDRO project.

The new homologous (Porjus U9) model turbine, including a Kaplan runner with six moveable blades and with a reference diameter of 400 mm, was installed in the Vattenfall test rig Q1, 2021.

The model turbine is prepared with many taps for pressure and velocity measurements and also have several observation windows to allow visualization of different flow phenomena.
Furthermore, the model is prepared for PIV (Particle Image Velocimetry) measurements, i.e. to measure and study velocity fields at the inlet, vane less space (between the guide vanes and the runner) and to downstream the runner in the draft tube.

For the AFC4HYDRO project also an additional draft tube cone was manufactured, allowing flexible installation of the ICM and the IPM systems. The draft tube cone also includes several taps for pressure and velocity measurements and have further windows for visualization used for validation of numerical models.

Figure 1. Porjus U9 model turbine installed into the test rig structure with ICM & IPM.

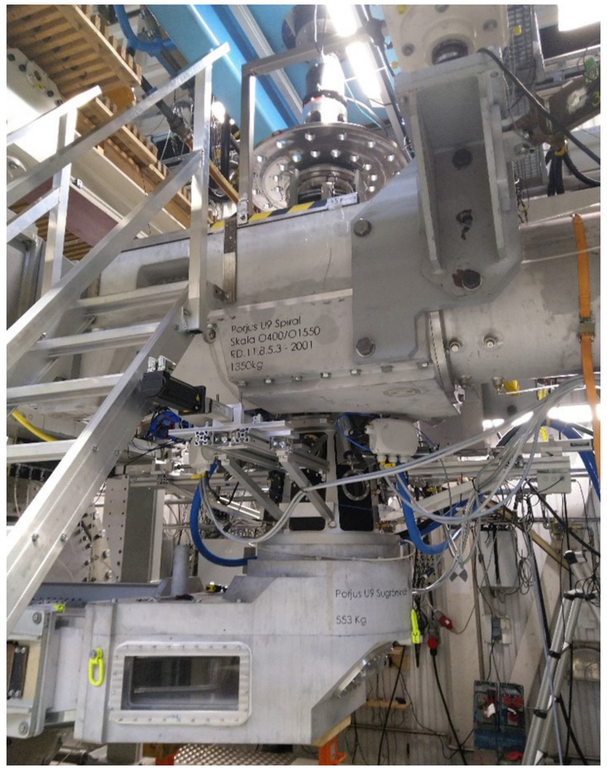


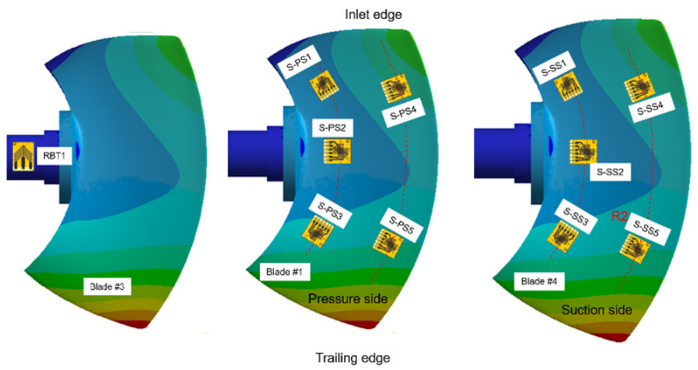
Figure 2. Assembly of the draft tube cone.

Figure 3. Draft tube cone assembled with ICM & IPM systems.

Since the installation of the model turbine, a lot of work have been done to calibrate all sensors and to prepare the data acquisition system.
In total the test rig and the model turbine is equipped with about 200 sensors measuring the performance of the turbine, the hydraulic conditions in waterway and structural response in the model runner, shaft train and test rig structure. In addition, our AFC4HYDRO partners have extra sensors that are also synchronized (in time) with Vattenfall's data acquisition system.
Time resolved data from these sensors results in a tremendous amount of data which also require large storage capacity and tools and algorithms for efficient postprocessing and analyzing of data.

For measurements in the rotating system, we use a telemetric system consisting of totally 40 channels, used for strain gauge measurements on the runner blades and the turbine shaft. Two additional blades will also be equipped with custom made pressure sensors (ø3 mm) but will be used and tested separately due to limitation in the telemetric system.

In Q2 we began to perform experimental modal analysis in the test rig to study the structural response in the runner and the shaft train to validate numerical models. Moreover, for load scaling purpose of characteristic load measured on the runner and the shaft and depending on the structural model design, we will further investigate how



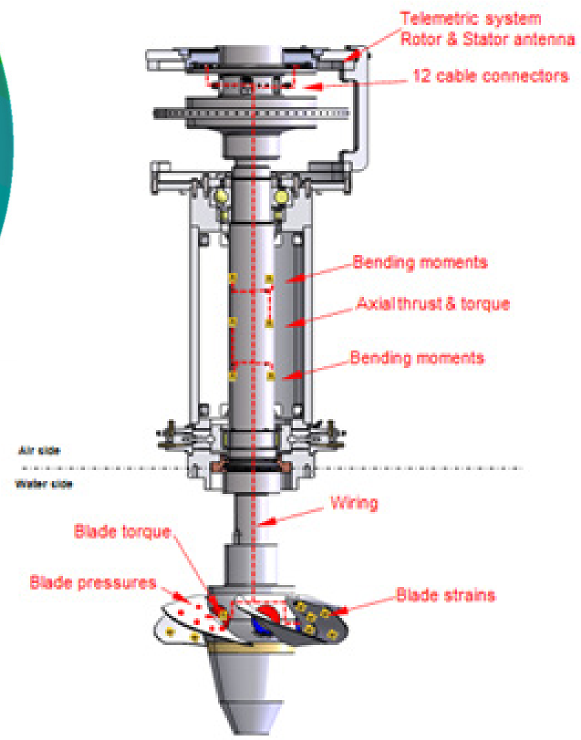
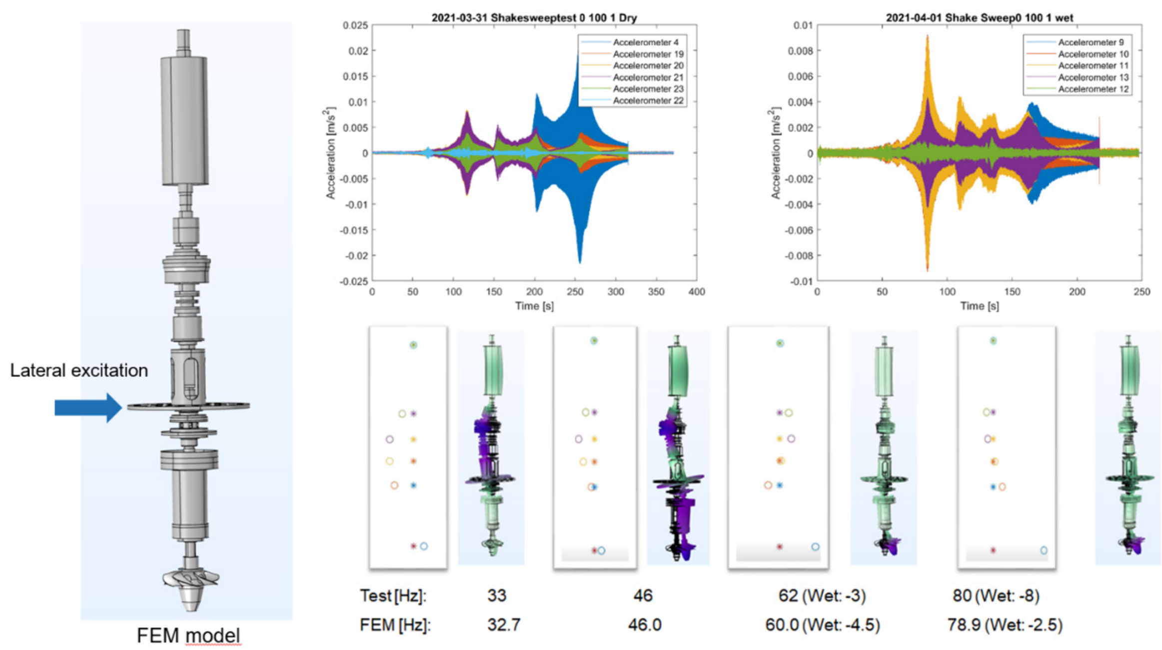


Figure 4. Strain gauge sensor locations on the runner blades and the turbine shaft.
Figure 5. Pressure sensor locations.

the structural response from excitations originated from the runner, waterways or the AFC4Hydro subsystems (ICM, IPM) will be influenced by its modal characteristics. Depending on the ratio between the excitation frequency and the eigenfrequencies, damping or amplification can occur for the measured quantity.

Another perspective of experimental modal tests and numerical simulations is the safety for all personnel working in the project. For example by having a good understanding of the risk for dangerous resonance phenomena for various types of excitation.

Figure 6.
- Left: FEM model of shaft train & location of experimental excitation.
- Middle: Results from numerical and experimental modal analysis.

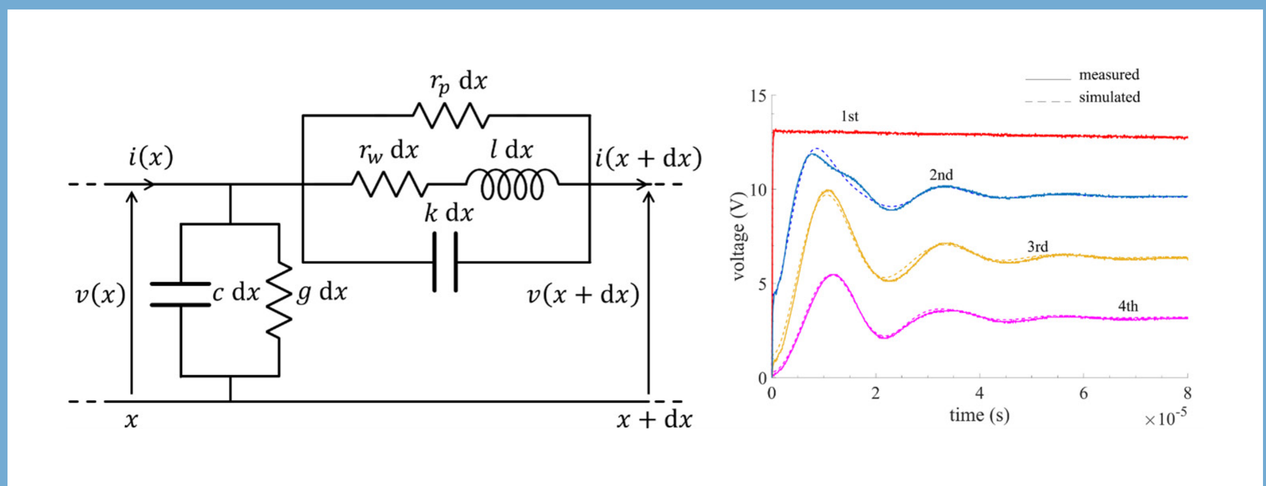


4 | PHD CANDIDATE

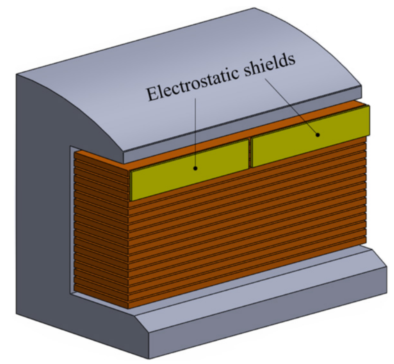
ROBERTO FELICETTI, UPPSALA UNIVERSITY

The new generation of more flexible hydropower stations must be a more reliable one. Synchronous generators and motors (SM) are called to start and stop more frequently than in the past becoming more exposed to thermal and mechanical stress. Some innovative researches on the excitation system (ES), such as the unbalanced magnetic pull compensation, the split rotor excitation, as well as the replacement of some damper bar performances through the active field current control, show a potential to reduce the above mentioned issues. Nevertheless, the effects of applying a modern fast switching power electronics (PE) to a more than a century old technology needs to be first studied and assessed.

Figure 1. Field winding model and comparison between measured and simulated voltage transient.



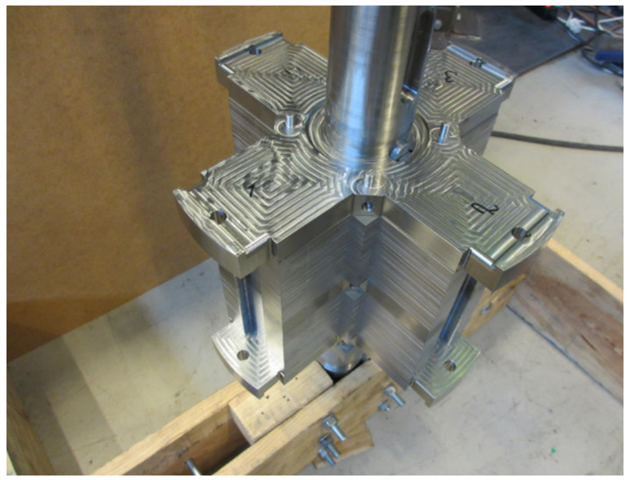
The first part of my work under task 4.2 WP4 of the HydroFlex project has been to determine the parameters of the field winding and of the PE which affect the voltage surges and voltage gradients in the rotor winding of salient pole wound SM. An electric model for reproducing the influence of said parameters has been carried out and tested (Fig.1) together with the experimental setups to be used.



The outcomes of this study offer solutions for mitigating or preventing rapid voltage edge related stress in the rotor insulation, such as reducing the capacitance of the field winding towards the machine frame, increasing the turn-to-turn capacitance by means of electrostatic shields (Fig. 2), adopting a multilayer winding and coordinating the commutation time of the PE with the Eigen-frequencies of the field winding.

The second part of my work focuses on achieving new and additional performances for the excitation system of SM by rapidly controlling the field current through the PE. In particular the start of the machine by AC feeding its rotor and the active damping of the rotor oscillations. To this end the design and the construction of a laminated rotor (fig.3) for a 60 kVA test SM is ongoing. Tests and results will be first available in 2022 when the machine construction will be completed.

Figure 2. Pone of the measures for attenuating the high voltage gradient in the field winding.
Figure 3. The laminated rotor prototype and structure of the 60 kVA synchronous test machine which is going to be wound



AFC4HYDRO ACTIVITIES

5

SHM TESTING

AT ÄLVKARLEBY

The UPC team travelled to Sweden in order to take part in the first test campaign of the AFC4Hydro project. All the subsystems (ICM, IPM and SHM) developed in the scope of the AFC4Hydro project were tested on a reduced scale Kaplan turbine model located at the Vattenfall Research and Development center at Älvkarleby. UPC was in charge of validating the structural health monitoring system (SHM) under a wide range of operating conditions.

Since the AFC4hydro project aims to extend the turbine operating range to conditions in which the fluid loads are far more aggressive than in the best efficiency point (BEP), measuring the dynamic response of the turbine is of paramount importance.
Therefore, experimental modal analyses (EMA) of the Kaplan turbine in a wide variety of configurations (different runner blade angles, different pressure levels and runner blade-free surface distances) were carried out at the beginning of the test campaign.
During these tests, the modal response of the turbine, and in particular of the runner blades, was observed to be dependent on both the runner blade angle and the runner blade-free surface distance.

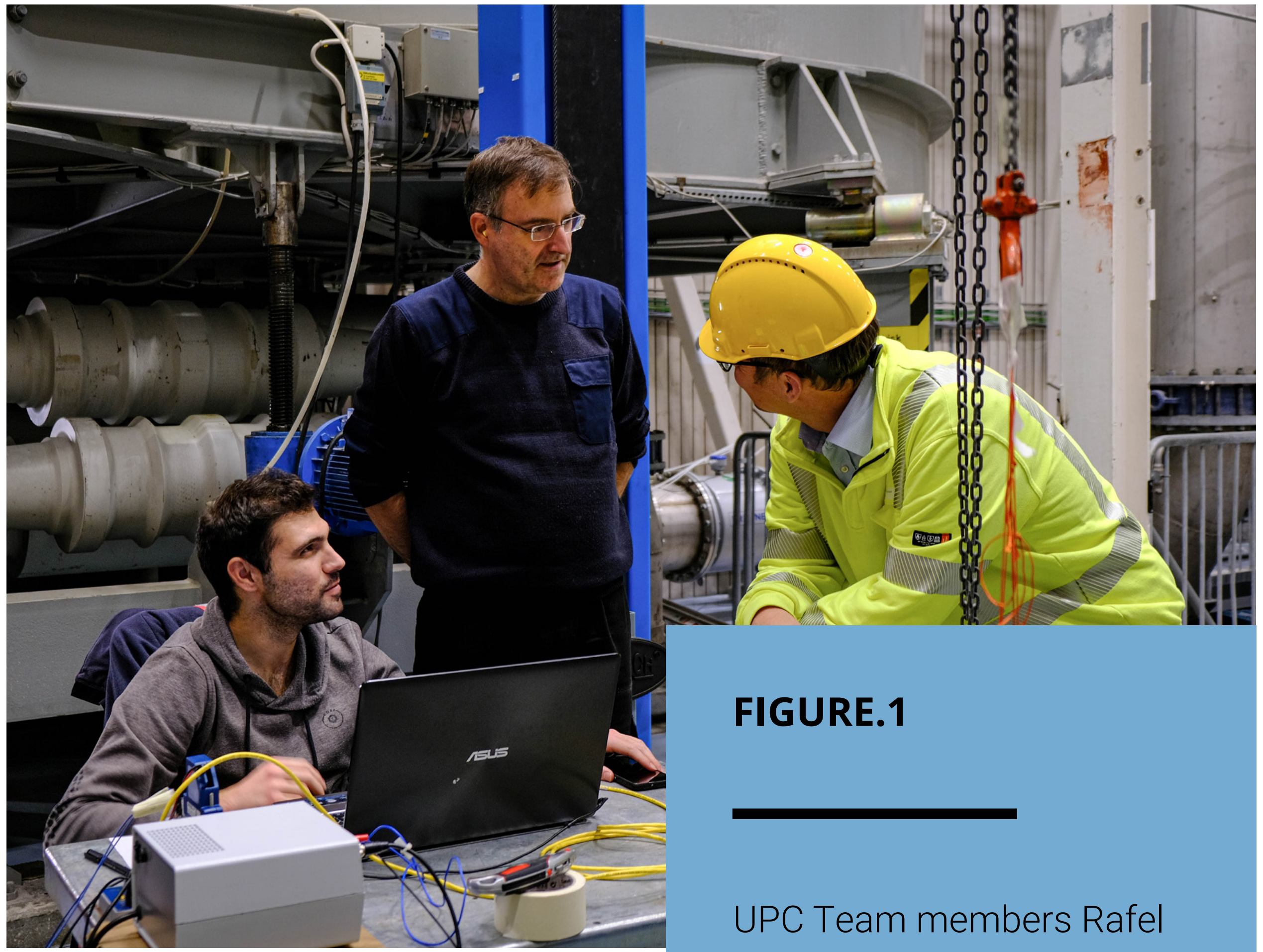


FIGURE.1

UPC Team members Rafel Roig Bauzà and Xavier Escaler working toghether with other AFC4Hydro partners.

In order to better understand the effects of these variables in the dynamic response of blades, two separate experimental setups were designed.
These setups were built to significantly reduce (or eliminate if possible) the influence of the many other variables affecting the dynamics of the blade when installed in the runner and leave it depending on solely the two variables of interest, namely: blade - free surface distance and blade angle.
In the first experiment, UPC assessed the influence of the blade-free surface distance on the dynamic response of a single blade. For that, the blade was hung from a crane using two ropes.

Two methods were used to excite the blade, impacts by an instrumented hammer and chirp inputs by a PZT actuator glued to the surface of the blade. The former method was employed to test the blade in air and the later to test it in both air and water. Two submergible accelerometers were attached to the blade to measure the response.

To begin with, we carried out a roving hammer and a chirp test to determine the natural frequencies, mode shapes and damping ratios of the blade in air. Subsequently, the blade was tested using chirps while the water level was progressively raised. The evolution of the natural frequencies, damping ratios and mode shapes were calculated as a function of the submergence level from the results of this experiment.

In the second test, UPC investigated the effect of the blade angle on its dynamic response by means of a simplified system of three simultaneous blades as shown in Figure 3. During this test, only the blade in the middle position was instrumented. As in the previous test, an instrumented hammer was employed to excite the blade in air and a PZT patch in both air and water. Similarly, the response of the blade was measured with two submergible accelerometers.

Figure 2. Setup of the blade free test in air (a) and in water (b).

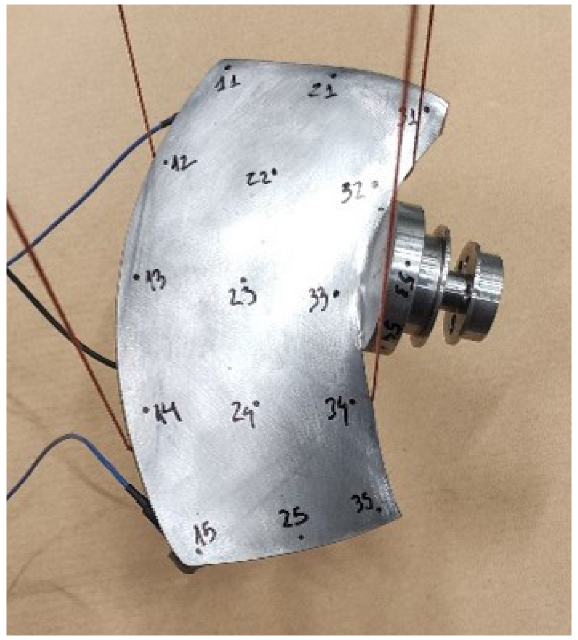


Figure 1. (a)

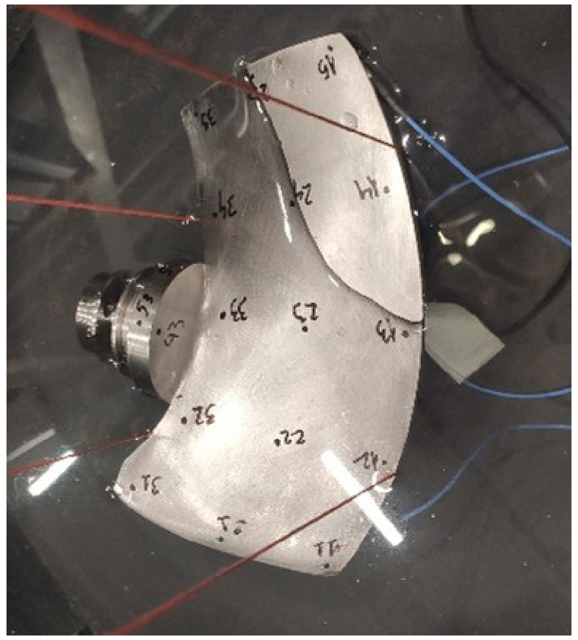


Figure 1. (b)

Figure 3 shows one out of the four blade positions considered during the test. The evolution of the natural frequencies, damping ratios and mode shapes were finally determined as a function of the blade angle.

These experiments were possible thanks to the technical support received from Vattenfall and specially from Mr. Carl Maikel Hogstrom.

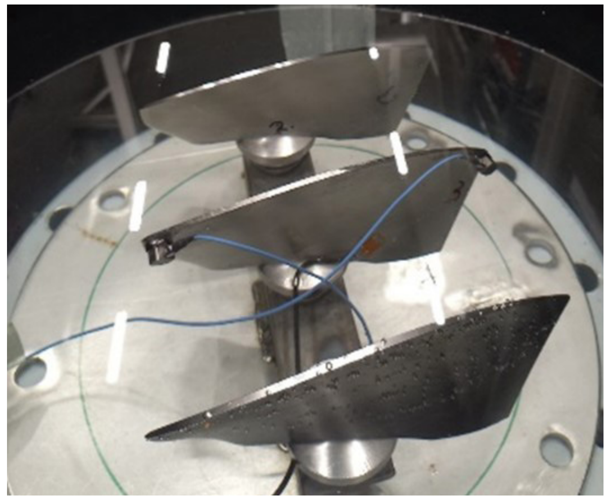
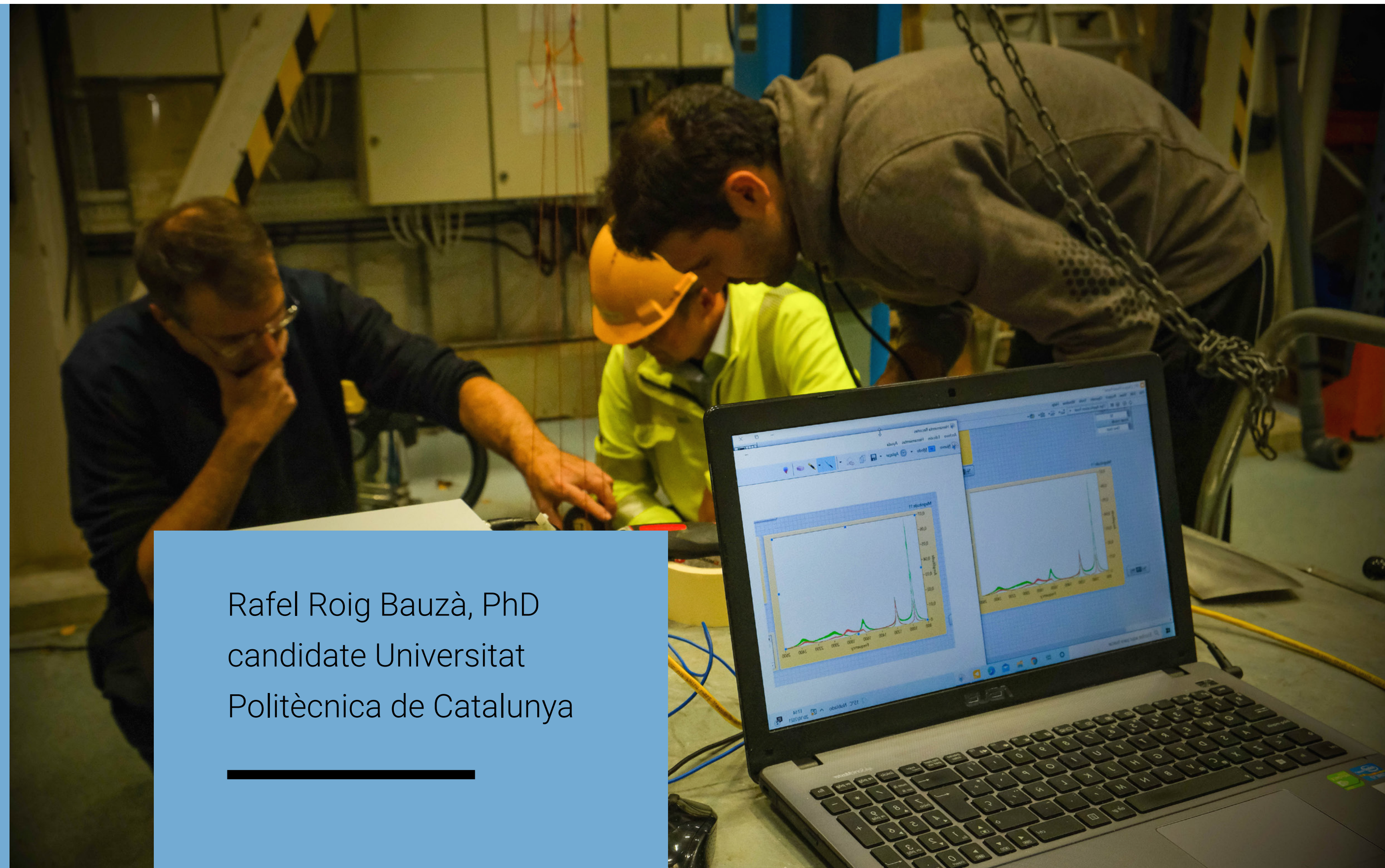


Figure 3. Setup of the three blade system test in water.



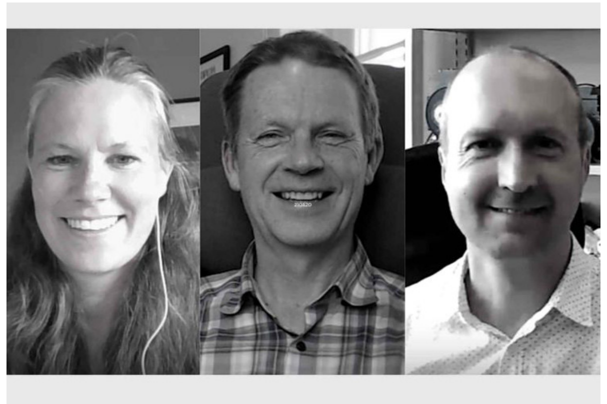
Rafel Roig Bauzà, PhD candidate Universitat Politècnica de Catalunya

6 | HYDROFLEX PODCAST SERIES

HYDROFLEX ACTIVITIES

Through The Research Council of Norway, NTNU together with Multiconsult have received additional funding to promote the Horizon 2020 project – HydroFlex in Norway. Due the Covid-19 a planned public workshop was converted into a podcast series.
The overall headline of the series is "Social values from hydropower". In collaboration with Norway's Polytechnic Society we have released three episodes so far.
These are:

1. **The history about hydropower in the Nordic countries,** with Ann Myhrer Østenby (NVE), Halvor Kristian Halvorsen (Hafslund Eco) and Hanne Cecilie Geirbo (OsloMet)



2. **The forefront of hydropower research,** with Ole Gunnar Dahlhaug (NTNU), Urban Lundin (UU) and Tone Knudsen (Statkraft)

3. **How does flexible hydropower secure supplies**, with Martha Marie Øberg (Statnett), Aslak Mæland (Statkraft), Linn Emelie Schäffer (NTNU) and Bjarne Børresen (Multiconsult)

More episodes are under development. The podcast series is currently in Norwegian only.

POLYTEKNISK

AFC4HYDRO ACTIVITIES

7 | ICM TESTING

AT ÄLVKARLEBY

One of the deliverables of the project includes testing on the Porjus U9 Kaplan model turbine at the Vattenfall turbine test facility in Älvkarleby Sweden. Installation of the various AFC4Hydro systems, including the ICM, started mid-September 2021 and the first round of comprehensive testing for the ICM ended mid-October.

The aim of AFC4Hydro is to pave the road for flow control technologies that will improve performance, flexibility of operation and lifetime expectancy of hydroturbine units. The project pushes its own solutions of such technologies, the IPM and ICM, and during testing performs mapping of characteristics before and after these technologies are applied.

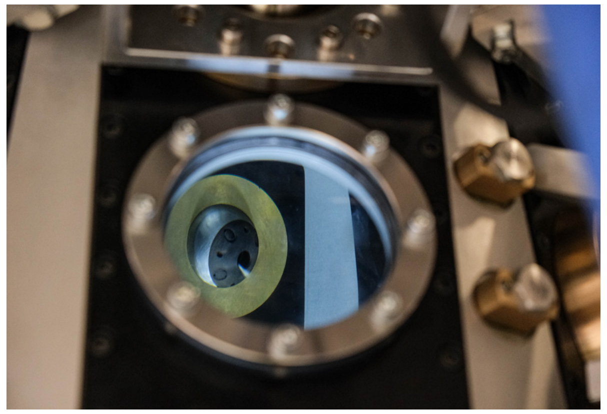
Figure 1-6.
FDB personnel working at the ICM system in the Vattenfall turbine test facility in Älvkarleby.

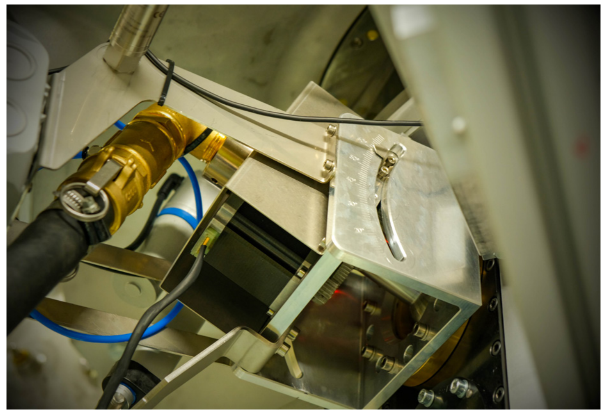
A main design principle is to minimize the effect of these technologies when not in need, typically around best efficiency point. This is almost true for the ICM; but we must leave "bumps" inside the flow to achieve the required and wanted degrees of freedom (DOF) when operating the ICM. The bumps will surely be given attention, but for now the effect of increased DOF is scrutinized.

During the initial trials the ICM proved to work according to expected principles and now allows the FDB team to further optimize and hone the solution. To operate this version of the ICM a comprehensive automation system, including controls and actuators, needs to be set into motion.

In addition, a pump-skid was built for the purpose of feeding the ICM nozzles. Science set aside, FDB also feel satisfied with the performance of all the auxiliary systems develop as part of the testing.

Being parties from abroad and wanting to exploit the experiments, we end up spending long hours per day in the lab. Still, we manage to meet more informally for dinners during the evenings. With Covid fresh in mind it is very satisfactory to finally meet and discuss over the table the findings of today and the plans for tomorrow. As for plans; the set-up produces vast amount of data, and I expect all the parties to dig deep into those and present findings in months to come.





Prof. Morten Kjeldsen,
WP2 leader
General Manager
Flow Design Bureau AS

AFC4HYDRO ACTIVITIES

IPM TESTING

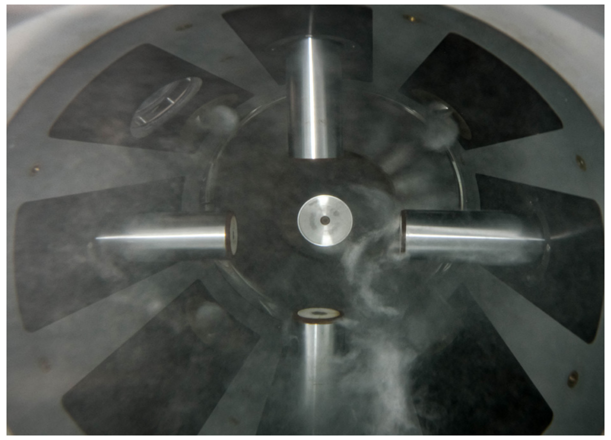
AT ÄLVKARLEBY

As part of the experimental campaign to investigate the feasibility of the AFC4Hydro subsystems at different scales, IPM (Injection of Pulsating Momentum) experiments were performed in September and October on the U9 turbine model at Älvkarleby by LTU in collaboration with Vattenfall Research and Development.

Aimed to mitigate the pressure pulsations caused by the rotating vortex rope (RVR), these experiments included stationary and oscillating protrusion of rods into the flow field inside the draft tube of the turbine.
In the case of stationary rod protrusion, different lengths were examined to compare the mitigation levels. While in oscillatory protrusion cases, different frequencies and amplitudes were attempted around fixed protrusion lengths depending on the operating condition.

Both approaches were tested at different levels of part load operation -determined by the opening angle of the guide vanes and for two different rod diameters.

The results obtained from the first experimental campaign are being analyzed at the moment, and they will provide the guidelines for the upcoming campaigns towards more functionality of the system and higher success in the mitigation of the RVR.



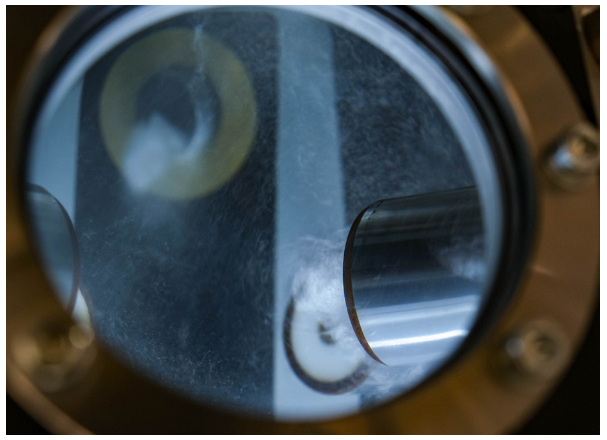


Figure 1 and 2.
IPM system mitigating pressure pulsation caused bt the RVR.

Shahab Shiraghaee,
PhD candidate Luleå
University of Technology

A brief review of

9 HYDROPOWER FLEXIBILITY research around the world

The importance of flexibility in the power system is an area of intense and active research worldwide. HydroFlex is far from the only research project in the world looking into hydropower and its role to provide flexibility into the power system. The following note gives a brief overview of other noteworthy or interesting projects around the world. No claim of completeness is given and apologizes offered to projects that may have been overlooked. In addition, there are many projects looking into power system flexibility from the grid perspective or by using other power sources.

Europe

In Europe, there are several Horizon 2020 projects covering various aspects of hydropower flexibility. The most notable projects (including HydroFlex and Afc4Hydro) is listed in table 1 below.

Table 1. Summary of Horizon 2020 projects related to hydro power and flexible operation.

HydroFlex https://www.h2020hydroflex.eu/	R&D project, financed by EUs Horizon 2020 program, aims to develop electromechanical equipment (turbine, generator, excitation, and converter) for 30 start/stop per day and higher ramping rates.
XFlex Hydro https://xflexhydro.net/	R&D project, financed by EUs Horizon 2020 program, to develop and test new and innovative technologies that will help hydropower adjust to its critical role integrating variable renewables into the system.
Afc4Hydro https://afc4hydro.eu/	R&D project, financed by EUs EUs Horizon 2020 program, design, implement and validate in full-scale water turbine an active flow control system that permit to increase efficiency and reduce the dynamics loads on the structure at any off-design operating conditions and during transient operations.
ALPHEUS https://alpheus-h2020.eu/	R&D project, financed by EUs EUs Horizon 2020 program, to improve reversible pump/turbine (RPT) technology and adjacent civil structures needed to make pumped hydro storage economically viable in shallow seas and coastal environments with flat topography.

USA

The National Renewable Energy Laboratory (NREL) is active in all renewable energy technology areas. Within hydropower the team is working actively on investigating hydropower's role in the next generation grid. This includes the HydroWIRES (Water Innovation for a Resilient Electricity System) Initiative is to understand, enable, and improve hydropower's contributions to reliability, resilience, and integration in the rapidly evolving U.S. electricity system.

Australia

The share of hydropower in the Australian electricity generation is low (6%). Rapid development of variable renewable energy has increased the focus on energy storage, including pumped storage hydropower (PSH). The Australian Renewable Energy Agency (ARENA) Is currently supporting several pre-feasibility studies for a different pumped storage schemes, including GIS study to map possible storage resources across the country as well as reuse of old mines for PSH.

China

China Institute of Water Resources and Hydropower Research (IWHR) has over 1300 staff members that are active in most aspects of hydropower. The rapid development of variable renewable energy has led to a change in operating pattern for existing and new hydropower, including peak shaving and frequency regulation. To strengthen the interaction with the power system one team has focused on improving the turbine governing system. This work includes amongst others developing better technical standards for turbine governors, modelling the hydropower system including the turbine governor and testing and validating the turbine governors.

International initiatives

Apart from the national and regional focus, two global initiatives are worth mentioning in the present context. Both may be designated compilation of best practices based on previous work rather than research projects.

Irena

The International Renewable Energy Agency (IRENA) is an intergovernmental organisation that supports countries in their transition to a sustainable energy future. Their work on renewable energy roadmaps have clearly shown the importance of variable renewable energy (VRE) in the future energy mix (60% in 2050). To effectively manage large-scale VRE several flexibility sources need to be exploited and planned ahead of time. The FlexTool, developed in collaboration with VTT Technical Research Centre of Finland, permits analysing different scenarios or solutions for developing flexibility. This includes looking at different scenarios for development of flexible hydropower.

IEA Hydropower

The IEA Technology Cooperation Programme (TCP) on Hydropower (also known as IEA Hydro) is a working group of the International Energy Agency's member countries and others that have a common interest in advancing hydropower worldwide. Annexe IX Hydropower Services, one sub-group of IEA Hydropower is working on the importance of flexible hydropower in the power system. By introducing a common nomenclature and performing surveys and case studies for different countries around the world, the importance of hydropower flexibility is clearly documented. The work also outlines important directions for future work, both for power plant owners, TSOs and regulators.

Bjarne Børresen,
WP6 Leader
Multiconsult

THANK YOU

EUROPEAN COUNCIL

NTNU

UPC

UPPSALA UNIVERSITET

CHALMERS UNIVERSITY OF TECHNOLOGY

SPV

LULEÅ UNIVERSITY OF TECHNOLOGY

FDB Flow Design Bureau

SINTEF

RAINPOWER

University of Strathclyde Glasgow

Lyse

NINA Norwegian Institute for Nature Research

VATTENFALL

Statkraft

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ABB

EDR MEDESO

IAEW Institute of Power Systems and Power Economics

RWTH AACHEN UNIVERSITY